Suspended Impurity in the Air.

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A study of the impurity in the air involves the measurement of quantity as well as the provision of means whereby the nature of the suspended matter can be examined. The object which the author had in view in making this investigation was to provide some simple and effective method for examining the quantity and nature of suspended dust, and its relation to visibility, fumes from industrial processes, dust produced in mines, fogs such as are experienced in our larger cities, and generally in the hope of throwing some light on problems which are concerned with the presence of fine suspended impurities in the air.

This paper is devoted chiefly to a description of a method of trapping for examination the suspended matter in the air, and the application of the method, and also to a discussion of the relation between dust and visibility. The work described by the author was carried out for the Advisory Committee on Atmospheric Pollution. This Committee has as its function the obtaining and consideration of data upon atmospheric impurities. The methods adopted fall into two distinct groups—the measurement and examination of:—

(*a*) Matter deposited from the air; and (*b*) Matter suspended in the air.

Filter Paper Method.

In order to measure the suspended impurity, a method was used in which a fixed volume of air, filtered through white paper, left a mark on the paper, the shade of which indicated the quantity present. This method owed its practicability to the fact that the suspended matter in city air is mainly derived from smoke and is thus black in colour, and the particles fairly uniform in size, so that in practical use it has been found that the discoloration as measured upon a scale of shades gives a reasonably accurate measurement of the quantity of impurity present.

An automatic instrument, operating on these lines, and designed by the author, has been in use by the Committee for some time, and as it gives automatically three or four records per hour, night and day, it provides a means of comparison of the quantity of impurity present at different hours.* The instrument has been fully described elsewhere, and as a result of its use

* 'Fourth Annual Report, Advisory Committee on Atmospheric Pollution.'

the suspended impurity in London and other cities where it is in operation has been shown to vary in a certain definite way. From midnight to about 6 A.M. it is a minimum, then rises rapidly to a maximum at about 10 to 11 A.M. on week-days and 12 noon on Sundays, after which it falls off. There is usually a slight rise about 5 P.M., and about 10 P.M. it drops rapidly till midnight. Thus there is a regular daily cycle. As stated above, this instrument is limited to the measurement of impurities which are sufficiently black for comparison with the standard scale. It is also open to the objection that the dirt trapped, being entangled in the meshes of the filter paper, cannot be subjected to microscopical examination.

Other Methods.

Many other methods of determining the amount of dust in the air have been used, perhaps the best known being the Aitken* dust counter, in which a measured volume of air is drawn into a small dust-free chamber, and by reducing the pressure within this chamber a deposit of moisture is brought about, the particles settling on a glass floor, where they can be counted. The assumption is made that each drop of moisture condenses round a dust particle; but this assumption cannot be justified, as condensation is known to occur in the absence of dust. Methods of filtration through soluble filters have also been used, such as collodion wool; these are subsequently dissolved in ether and the particles in a small measured volume counted (Hahn), or filtering through sugar and subsequently dissolving it in water. Methods such as these, in which the dust particles are ultimately suspended in a liquid, are clearly objectionable, as some of the suspended particles may be soluble in the liquid; also the particles composed of aggregates of finer pieces would tend to get broken up in the liquid, so that it is hardly justifiable to assume that the number obtained from the liquid suspension is a fair measure of the number suspended in the air.

The method of ascertaining the quantity of suspended matter by filtering a measured volume of air through weighed paper or other filter, and subsequently re-weighing is extremely difficult to apply, as the normal weight of impurity present in fairly dirty city air is of the order of 1 mgrm. per cubic metre, while a dense smoke fog contains approximately 4 mgrm. per cubic metre. Hence the filtration of large volumes of air would be necessary to get weighable quantities, and the time required for the filtration of such volumes precludes the possibility of ascertaining the state of the air by this method at any particular time. The automatic instrument above referred to was calibrated by using this method; that is, large volumes, amounting to

* 'Trans. Roy. Soc. Edinburgh,' vols. 30–36.

over 1000 cubic feet of air were filtered through discs of thick filter paper, in order to get sufficient quantity to weigh without too great an error.

A method has been used by G. T. Palmer* in which a quantity of air is drawn through a water spray, the number of particles in a measured quantity of the water subsequently counted, and the weight ascertained by evaporating and weighing the residue. This method obviously depends on the wetting of the dust particles by the water. It has been examined critically by Katz, Longfellow and Fieldner† with the result that the efficiency of the apparatus for stopping tobacco smoke is given as 13 per cent., while for fine silica powder suspended in the air the efficiency was 30 per cent. when the air was drawn through at 4 cubic feet per minute, and 20 per cent. at 3 cubic feet per minute, as examined by a light test. When examined by the weighing test the percentage of impurity stopped, when air was drawn at 4 cubic feet per minute, is given as 45.

It is extremely difficult to wet dry dust, and an apparatus depending on the wetting of dust particles by a spray is not likely to be very efficient. In this connection it may be of interest to observe that in the records of deposit obtained at the Committee's stations in different parts of the country, it has been found that while the deposit of atmospheric impurities which are soluble in water varies almost directly with the rainfall, there is no such relation between deposit of insoluble matter and the rainfall.

The exposure of plates or dishes to the air for a definite time has been used with a view to ascertaining the amount of dust in the air, but all such methods measure only deposited matter and consequently give no information as to the amount of dust suspended in the air. Speaking generally, any method which requires a long time for its application is of little use when the quantity of impurity in the air is subject to rapid variation.

Jet Apparatus.

The following method of obtaining a sample of dust from the air for measurement and examination has been evolved by the author, with a view to microscopic examination of the dust and in order to get an instantaneous value of the quantity of impurity.

A very small jet of air is made to impinge upon a glass surface, such as a microscope cover-glass, at a high velocity, under suitable conditions, when the dust suspended in the air carried in with the jet adheres to the glass and a record is obtained which can be removed and examined microscopically. In the first apparatus made the air jet was obtained by drawing air

* 'Amer. J. Pub. Health,' vol. 6, p. 54 (1916).

† 'Journ. Industrial Hygiene,' vol. 2, No. 5, p. 167.

out of a small cell, the floor of which was perforated by a round hole 0·15 mm. diameter, the roof being formed by a cover-glass at a height of 0·8 mm. above the floor. By making the floor of the cell out of a sheet of mica it was possible to observe the operation of the jet under the microscope.

On watching the cover-glass through a $\frac{1}{4}$-inch objective while air was drawn out of the cell, dust particles could be watched striking and sticking to the glass, and many of them were noted to be in the middle of small drops, presumably of water. The sensitiveness of this apparatus was so great that by clipping the end of an $\frac{1}{8}$-inch rubber tube communicating with the cell, pinching it between the finger and thumb, and then releasing it, a shower of dust particles was seen to strike and adhere to the cover-glass. The amount of air drawn through the jet thus was subsequently ascertained to be 0·15 to 0·18 c.c.; and the number of dust particles which struck the glass from this quantity of air was about 30, the test being made on a fairly clear day at Cheam, in Surrey, inside a room.

This apparatus had certain objections as, owing to its extreme sensitiveness, a very small volume of air only could be used and this might not be representative. Again, the size of the record obtained was so small that it was very difficult to find under the microscope, unless observed at the time of taking. This apparatus, when run in series with a paper filter, was found to be very effective in trapping the dust, a small proportion only escaping. In a test made in London in this way, two litres of air were drawn through the jet apparatus and then through a filter paper, and on subsequent examination a small pinnacle of black dirt was found deposited on the cover-glass immediately opposite the jet; this was about 0·2 mm. high and consisted of an almost perfect cone with its base on the glass. The conditions of impact of the dust particles, therefore, were altering during the test, starting by impact on a plane glass surface and finishing with impact upon the point and sides of the cone; thus the test made in this way was not regarded as a satisfactory one of efficiency, although it indicated that most of the dirt was removed from the air by the jet.

In a subsequent apparatus the hole for forming the jet was produced by cementing the two halves of a cover-glass, the edges of which had been ground smooth, over a hole formed either in a brass disc or in another cover-glass. This hole varied in diameter from 2 up to 11 mm., and the glass edges formed the sides of a slot and were adjusted to a distance apart of 0·1 mm. Thus the hole consisted of a long slot, 0·1 mm. wide and from 2 to 11 mm. long. This is shown in Fig. 1.

By using a jet formed by a slot of this type several advantages were

gained :—It was possible to find the record on the cover-glass after removal from the apparatus; also the volume of air used in taking the record could be increased and so made more representative. The actual volume used with a slot 11 mm. long, in London, is about 50 c.c., but the volume required depends upon the quantity of impurity present at the time; as it is essential that, for purposes of counting, the dust particles should not be too numerous. The number can then be ascertained by using a net-ruled micrometer eye-piece in the microscope.

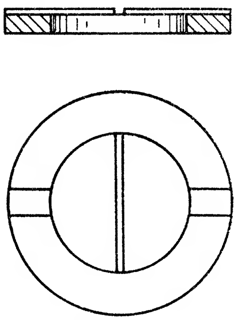
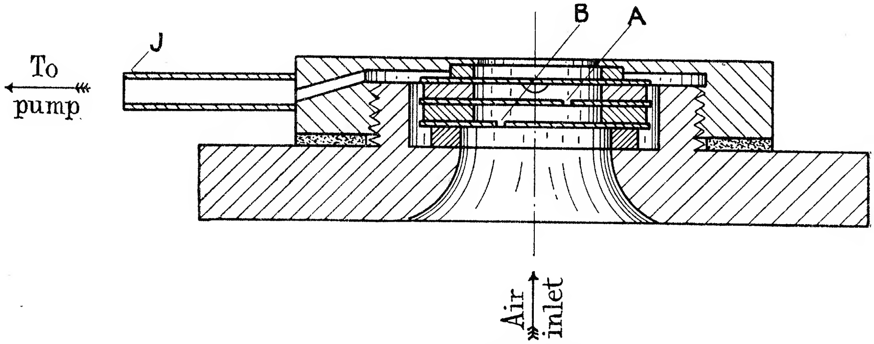


Fig. 1.

It is somewhat difficult to find a method of testing the apparatus for efficiency, but an arrangement was ultimately designed and made, as shown in fig. 2. Two cells were provided instead of one, the bottom cell had a slot, B, in its floor a little to one side of the centre. The floor of the bottom cell was formed of the two halves of a cover-glass, cemented to a flat brass



Double cell

Fig. 2.

ring to form the slot, the edges of which were ground smooth and straight. The roof of the bottom cell was similar to its floor, but had a slot, A, upon the opposite side of the centre. The roof of the upper cell was formed of a cover-glass, and each cell was 1 mm. deep. This apparatus could be placed upon the stage of the microscope and kept under observation while a record was taken. The tube J communicated, through the annular space around the top cover-glass, with the upper cell; the joint between the roof and floor of the lower cell was made air-tight. By drawing air from the upper cell it entered through the slot B in the floor of the lower cell, the jet striking the roof of that cell, and the air then passed through the slot A

in the roof of the lower cell, the jet striking the roof of the upper cell. Thus, if all the dust in the air were trapped in the lower cell, no dust would appear upon the top cover-glass, also if a suitable volume of air be drawn through, the number of particles upon the cover-glass forming the roof of the upper cell, compared with the number upon its floor, would give an indication of the efficiency of the jet. The apparatus was made and used in order to ascertain the efficiency of the jet, and also to determine the most suitable size of orifice to use. The results so far indicate that under suitable conditions, the first cell traps practically all the dust particles.

If the percentage of the total caught by the jet is less than 100, but remains constant, then let :—

T equal the total number of dust particles in the air drawn in.

C_1 equal the number caught on roof of first cell.

C_2 equal the number caught on roof of second cell.

Since C_1 and C_2 bear the same ratio to the number in the jet

$$\frac{C_1}{T} = \frac{C_2}{T - C_1}.$$

Therefore

$$C_1T - C_1^2 = C_2T \qquad \text{and} \qquad T = \frac{C_1^2}{C_1 - C_2}.$$

Thus the total T can be found. Similarly, if the proportion of the total which is caught is constant, this proportion can be found once for all from the observed value of C_1 and calculated value of T, *i.e.*, C_1/T.

The following Table gives a few values of efficiency as calculated from the above method :—

Volume of Air Aspirated in each Test = 1000 c.c.

Experiment number.	Count per strip across record.		Efficiency percentage of jet calculated from the formula $T = C_1^2/C_1 - C_2$.	Velocity in jet in metres per second.
	Top cell.	Bottom cell.		
1	143	816	82·5	Approx. 90
2	258	700	63·6	„ 90
3	95	500	81·0	„ 90
4	170	1200	81·4	„ 90
5	300	1200	75·0	„ 90
6	160	338	52·7	„ 90

This method of testing is not quite satisfactory, as the conditions are not the same as when a single jet is used. The resistance of the two slots probably reduces the velocity below that in the single-slot apparatus, and, as

shown later, the efficiency falls off rapidly as the velocity is reduced. It is probable, therefore, that the actual efficiency is higher than indicated by the double-cell method. A convenient method of drawing the air through the jet is by means of an air-pump having a displacement of 50 c.c.

By testing with the double cell above described, it was found that the most efficient diameter of circular hole was about 0·15 mm.; for example, a jet 0·076 mm. in diameter trapped a lower percentage of dust particles. In the case of the slot-shaped holes it was found that about 0·10 mm. was the most efficient width; for example, reducing the width to 0·04 mm. gave a less efficient result.

A curious phenomenon was noticed in the test for efficiency above described. Occasionally the second cell collected no particles whatever, that is, all were trapped in the first; while at other times about 30 per cent. of the particles penetrated to the second. A test on October 26, during a smoke fog in London, gave 100 per cent. efficiency, *i.e.*, all the particles were trapped in the first cell. There appears, therefore, to be some variable condition which affects the adhesion of the particles, and from subsequent experiments this condition appears to be the humidity of the air; an attachment was therefore made by means of which the air was made to approach the jet through a damp-walled chamber in order to raise the humidity and keep the air as nearly saturated as possible. The tests of efficiency here given were made without the moist chamber.

Another method for examining the efficiency by means of the double cell has been applied; that is, a record was taken with the double cell and counts made; then, using the formula given on page 23, the total number of particles calculated. A second record, taken at the same time with a single cell, was then counted and the result compared with the total obtained as above described. By this method a figure was obtained which agreed well with the values of efficiency already given. The numbers in one particular experiment were as follows:—

Number of particles per cubic centimetre from count of record in single cell, 620.

Number of particles per cubic centimetre from count of record in double cell, 756.

Efficiency from these figures = 82 per cent.

When observing the action of the double cell it was clear that only the finer particles escaped from the lower cell, and not many of these. The efficiency, as estimated from counting, would therefore be lower than if estimated on a weight or volume basis.

In an attempt to estimate the efficiency by comparison with a count of particles using an ultra-microscope, it was found that the number of particles as counted under the microscope, while in suspension, was much less than the count obtained from the jet. The ultra-microscopic method is subject to the objection that an extremely small volume of air is used, and it may not be representative; but this result suggests also that the visibility of the particles may be reduced while in suspension owing to Brownian movements.

The final form of the jet apparatus is shown in fig. 3. The apparatus consists of a brass sleeve B, into the upper part of which is screwed a plug C, which makes an air-tight joint with the sleeve by means of a leather washer H. Into the lower opening of the sleeve is screwed a brass piece K, perforated by a funnel-shaped hole, varying in diameter at its narrowest place from 2 to 10 mm., according to the length of the slot to be used. The slot for forming the jet is shown at A and is formed by a diaphragm of hard brass or copper-sheet in two half-discs, the straight edges of which form between them the slot. This diaphragm is held in place by a brass ring by means of four screws which permit the setting of the slot to the correct width. This brass ring is of suitable diameter to receive a $\frac{3}{4}$-inch cover-glass in a recess formed upon its upper surface, and it is perforated by a central hole of the same diameter as that in K; thus a slot is formed the length of which is determined by the diameter of this hole. In order to hold the cover-glass in position over the slot a spring washer D is fixed upon the lower end of the plug C. A connection E is fixed on the side of the sleeve B for an air-pump, of suitable capacity, usually 50 c.c.

To the outer part of K is fixed a thin brass tube T, of a capacity of about twice that of the air-pump. This tube is lined with blotting-paper U, held in place by two wire rings. Before taking a record this blotting-paper is saturated with water, the function of which is referred to below. This makes a convenient form of apparatus and its sensitiveness can be adjusted by using slots of different lengths, but for use in city air a slot 1 cm. in length is found suitable, the volume of air used being 50 c.c. When in very clean air a shorter slot, say 2 mm., may be used, or a greater volume of air drawn through.

Flow of Air in Jet.

The velocity of flow of air through an orifice is a function of the difference in pressure between the two sides of the orifice, but has a limiting value when the pressure on the low side is 0·527 of that on the high, the maximum velocity obtainable being the velocity of sound in the jet. The velocity of sound in dry air at 0° C. is $3 \cdot 3133 \times 10^4$ cms./secs. and through a jet 2 mm. long and 0·1 mm. wide, measured approximately by taking the time required

to pass 50 c.c., was about $2{\cdot}5 \times 10^4$ cms./secs. Thus it is approaching the limiting velocity, and is of a very high order, being, in rough figures, about

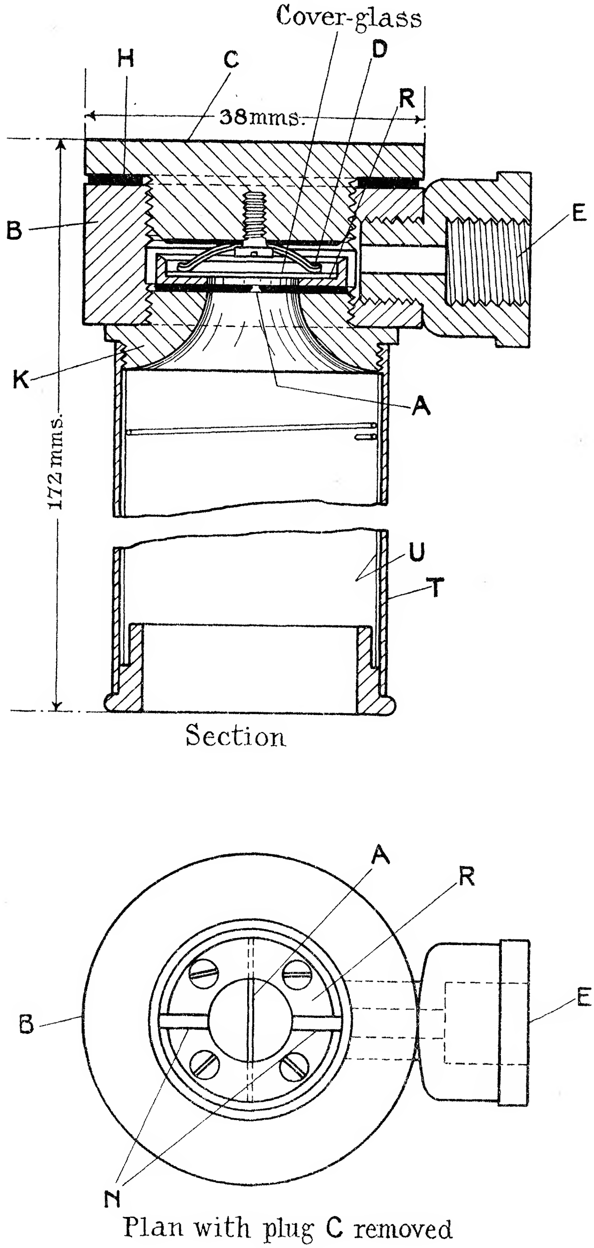


Fig. 3.

10 miles per minute. As the velocity was measured at atmospheric pressure, if account be taken of the expansion due to fall of pressure in jet,

it is probable the true velocity is equal to that of sound. The particles of dust which are drawn through with the jet, therefore, travel at an exceedingly high velocity, and when the jet is deflected on striking the plate, these particles are projected against the glass, where they adhere.

Adhesion of Dust Particles to Glass.

Why dust particles projected against the glass should adhere is not very obvious, but certain explanations suggest themselves; for example, to produce the jet the air in the cell has its pressure reduced and there is a fall of pressure in the jet, due to the high velocity; this doubtless results in moisture being condensed around some, if not all of the dust particles at the moment, or just before the moment, of striking. That this action does take place is obvious on watching the process through a microscope, as some of the particles can be seen surrounded by water. This is the same effect as is produced in the Aitken dust-counter, but the quantity of moisture so condensed is extremely small and, when the cover-glass is removed from the apparatus for counting, it evaporates rapidly; thus there need be no confusion over the counting of water drops as dust particles.

The function of the tube T is to saturate the air with water before it is drawn through the jet. In operation two or three pumps-full of air are drawn in before the cover-glass is placed in position, thus filling the tube T, with air to be tested. The cover-glass is then placed in position in its recess over the slot, the plug, C, screwed home, and 50 c.c. of air are drawn through the slot as rapidly as possible.

It was found in experimenting with this that if the tube T were held in the hand so as to be slightly warmed, a visible mist appeared in the tube, and a record taken under those conditions was spoiled by the water drops washing away the dust in streams, and thus making it impossible to count. When, however, the tube is kept cool so that no visible mist is formed this difficulty does not arise; it has been found that the addition of the tube makes the apparatus more efficient. It seems probable in the light of this that some of the variations in the amount of dust shown in Table I were due to variations in moisture-contents, as the jet used had not the attachment referred to. Owing to the great variations noticeable between records taken with and without the tube T, there appears to be little doubt that the chief cause of adhesion of the dust particles is condensation of water upon them as they pass the jet and the pressure is suddenly reduced.

As bearing upon the effect of the velocity of the jet it appeared possible that there might be an observable effect if the velocity could be varied, and to examine this several experiments were made in which air was drawn through

the jet at different rates, other conditions being the same, and the number of particles adhering to the glass counted. The results of these tests were as follows:—

Jet used—2·42 mm. long by 0·135 mm. wide.

Experiment number.	Volume in c.c.	Time of flow in seconds.	Average count per square.	Method of aspirating.	Approximate number of particles per c.c. calculated from count.	Velocity through jet in metres per second.
(*a*)	50	1	100 (estimated)	Pump	140	160
(*b*)	78	10	34	Gas burette	31	25
(*c*)	62	15	10	" "	11	13·1
(*d*)	50	1	100 (estimated)	Pump	140	160
(*e*)	83	10	26	Gas burette	22	26
(*f*)	78	20	14	" "	13	12·5

It appears certain, therefore, that the velocity of the jet has a profound effect upon the result obtained, and it is necessary to keep the velocity as high as possible in order to get the greatest efficiency. In view, however, of the condensation effect referred to above, it is possible that some of the results attributed to varying velocity may be due to the fact that a low velocity implies a small reduction of pressure, whereas a high velocity implies a greater reduction, and thus the condensation of water may be dependent upon the pressure.

A somewhat curious phenomenon, the cause of which is not yet very obvious, is the occurrence of flocculated masses on the records. When the air is drawn through the jet at a low velocity (about 7 to 8 metres per second) the records consist sometimes of practically nothing but masses of particles collected together in lumps; these are referred to in Table I as aggregates. A record taken at the same time, using a high velocity of about 170 metres per second, showed practically no aggregates and consisted entirely of fine particles scattered uniformly. This appears to indicate that the aggregates are formed in the jet and do not exist in the air before aspiration; it also suggests some electrical effect, perhaps due to the rapid flow in the jet.

Application.

Visibility and Dust.—It appears probable from the tests already made by the author that the presence of suspended dust in the air is one of the chief factors governing visibility on occasions when there is no fog to obliterate vision at short distances. On several ocasions when the visibility was bad, and a distinct grey or bluish haze was seen against distant objects, tests taken

revealed the presence of abnormally large numbers of dust particles. During last August, while on a holiday in Norfolk, samples of the air were taken daily and the relation of the quantity of dust to the visibility roughly estimated. With the exception of August 25, not yet accounted for (probably due to variation in relative humidity), and another day when there was a water mist, the visibility appeared to be a function of the number of suspended particles. It would seem, therefore, that there is a useful field of application in attempting to relate the quantity of suspended matter with visibility.

Expired Air.—Another application of the apparatus is to the examination of expired air, with a view to ascertaining whether the suspended impurities in the air breathed are retained or expelled. Experiments made on this indicate that the tidal air expired contains a large proportion of the suspended matter which was inspired, while the "reserve" air from the deeper parts of the lungs, while containing very much less than the tidal air, still does contain some of the suspended matter breathed in. An important result obtained was that the quantity of dust in the deep parts of the lungs depended chiefly upon the nature of the breathing, that is deep breathing from any cause carried dust into the deeper parts, and even the last part of reserve air under such conditions was found to be laden with dust.

Examination of Fumes, Mine Dust, etc.—As a means for rapidly sampling fumes from different sources for microscopical examination, the jet arrangement should be useful. The same applies to mine dust, or dust from other sources; the chief points of advantage being the possibility of instantaneous sampling of the air, and the fact that the records obtained can be preserved for future reference, while the dust particles are not acted on in any way, such as by suspension in liquid which precludes the possibility of measuring soluble dust.

Vertical Distribution.—The examination of the vertical distribution of suspended matter in the air is another use to which this apparatus may be put. The whole apparatus is very small and light, and the records can be taken in a few seconds, so that it would be a simple matter to take it up in an aeroplane or balloon and obtain samples at different heights, preserving the records for examination later.

These are a few of the applications which suggest themselves at the moment; and, as illustrating the use of the jet, a description will be given of an examination of the suspended impurity and its relation to visibility and wind direction.

Transport of Suspended Impurity by the Wind.

It is well known that the chief source of suspended atmospheric impurities in this country is the burning of smoky fuel. The seasonal variation is very well marked, the quantity of impurity falling off to a minimum in the summer and rising to a maximum in the winter, when all the domestic fires are in full operation. There is a similar relation in the hourly variation, the only period comparatively free from smoke pollution being the small hours of the morning when fires are out. The distance to which smoke impurities travel from their source is not known.

For some years the author has noticed that when the meteorological conditions were suitable, usually in anti-cyclonic weather, with gentle easterly or north-easterly winds, it was usual to find a bluish haze overlying the whole country. By the aid of the filter already mentioned, this haze was found to be composed of solid particles which gave a distinct discoloured record on the white filter paper. It is a matter of conjecture where these particles come from, but the author would hazard the statement that they are often derived from the smoke of Continental fires. From observations made during last August, it appears highly probable that the great industrial effort now being made by Germany is, under certain conditions, responsible for a fair proportion of the suspended impurity in the air over this country. The method of observation on which this statement is based was as follows:—

Records of suspended dust were taken daily on the coast of Norfolk during last August, close to the edge of the sea. The records were preserved, also careful notes of the wind direction and velocity each day. The Daily Weather Maps issued by the Meteorological Office, indicated the wind direction over a large area, and thus the direction from which the impurity came.

The results of these experiments are set forth in Table I.

All the records tabulated were taken at Holme, Norfolk, on the sea coast, the exact position being indicated in the Table, but in no case was the distance from high-water mark more than 150 yards, the intervening space being covered by marram grass and fir trees, so that there was no source of dust.

Volume of Air.—The volume of air drawn through the jet was varied from 100 c.c. up to 1000 c.c., the smaller volume being used with the hope of being able to make a count of the particles.

Visibility.—The figures given for visibility are those for Pulham, which was between 40 and 50 miles away, and therefore the conditions were probably not the same as at Holme, where the records were taken; the figures are inserted as having been taken by a skilled observer at the Meteorological

Table I.—Records of Dust Suspended in the Air taken at Holme, Norfolk, August, 1921. Jet Apparatus.

Date (August, 1921).	Conditions of Observation.				Time (G.M.T.).	Volume of air used.
	Place.	Weather.	Visibility at Holme.	Visibility at Pulham at 13 h. M.O. code.	h.	c.c.
13	Land side of sand hills...	Blue haze, sunny, some clouds, thunderstorm 14 h.	—	7	14	200
13	Low-water mark	Blue haze, sunny, some clouds, thunderstorm 14 h.	—	7	15	1000
18	Sand hill	Sunny, haze, thin cirrus clouds	Sea horizon invisible	8	11½	200
18	,, ,, ...	Sunny, haze, thin cirrus clouds	,, ,, ...	8	17	100
19	,, ,, ...	—	Sea horizon invisible 10 h., just visible 19 h.	9	12½	100
20	Edge of sea	Fine, sunny, cirrus clouds, heavy haze	Sea horizon invisible	8	12¼	100
24	Sand hill	Damp, overcast	—	5	16½	1000
25	,, ,, ...	Sunny, slight haze	—	7	19½	500
26	,, ,, ...	Very little haze	Good	9	16¼	Up to 1000
27	Land side of sand hills...	Sunny, haze nearly gone	,, ...	9	16	1000
27	,, ,,	,, ,,	,, ...	9	16	1000
28	Sand hill	Very little haze, sunny; light cirrus from S.	Very good; Skegness visible, also sea horizon	8	16¼	1000
29	,, ,, ...	Bright sun, clouds, marked haze	Sea horizon just visible, not Skegness	8	13	100
30	Water edge	Cumulus, sunny intervals, some haze	Skegness just visible	8	13¼	1000
31	Land side of sand hills...	Sunny; light cirrus from W., dense haze	Very bad, sea horizon invisible	8	10¼	1000

Table I.—(*continued.*)

Microscopic Examination of Suspended Particles.

Date (August, 1921).	Method of mounting.	Slide number.	Number per c.c. from count under microscope.	Number corrected for loss in Canada Balsam.	Range of shape and size.	Average diameter.	Nature of particles.
					microns.	microns.	
13	Canada Balsam	1	65	150	0·85–0·34	0·5	No crystals, no aggregates; fine dark-coloured dust.
13	,,	5	Over 200 (too many to count)	—	1·70–0·34	0·5	No crystals.
18	,,	8	72	168	1·40–0·34	0·5	Very uniform in size; no crystals, no aggregates.
18	,,	13	133	310	1·40–0·34	0·5–0·7	Very uniform in size; no crystals, no aggregates.
19	Dry	19	100	—	0·85–0·34	0·5	Rounded; no aggregates, some crystals.
20	,,	22	145	—	1·40–0·34	0·5	Some crystals, no aggregates.
24	Canada Balsam	26	30	70	1·70–0·85 (Spheres grading to 0·34)	0·5	Some spherical.
25	,,	28	130	304	1·70–0·34	0·5	All rounded; some perfect spheres.
26	,,	33–37	Not enough to count	—	—	—	
27	,,	41	12	28	Spheres 1·4 (grading to 0·34)	0·5	All rounded; very variable in size.
27	Dry	41	28	—	1·4–0·34	0·5	No crystals, all rounded; large spheres grading to smallest particles.
28	Canada Balsam	43	—	17	Up to 1·7	0·5	Irregular in size and shape; a few aggregates.
29	Dry	48	186	—	Spheres 1·7–0·85 down to particles 0·34	0·5	Big; rounded and very variable in size; some drops.
30	,,	52	34 (excluding drops)	—	1·7 (grading to 0·34)	0·5	Very variable in size; many drops present, crystallising on standing.
31	,,	55	Over 200 (too many to count)	—	Max. 2·55 (grading to 0·34)	0·5	Very variable in size; some spheres; many aggregates.

Table I—(*continued*).

Wind direction and velocity in miles per hour								
At ground level.								At 1000 feet.
Date (August, 1921).	Holme at time of taking records.		Pulham at 13 h.		Pulham at :— 18 h. Near time of taking records.			Pulham near time of taking records.
		mi/hr.		mi/hr.		mi/hr.		mi/hr.
13	W.		0	0	W.	1–3		15
13	—		—		—			—
18	N.E.	8·5	E.N.E.	13–18	E.N.E.	15		24
18	N.E.	12·8	—			10		12
19	N.N.E.	12·8	E.N.E.	19–24	N.E.	13		13
20	N.E.	12–14	N.E.	8–12	—	5		7
24	N.-N.W.	—	N.N.W.	8–12	N.E.	8–12		3 (at Howden).
25	W.	—	W.'S.	8–12	W.	10		15
26	S.W.'W.	10–13	W.	8–12	W.'S.	8		13
27	W.*	—	W.'S.	13–18	S.W.	20	(Howden at 17 h.)	30 (at Howden).
27	W.	—	—		—			—
28	N.-N.E.	0–8	0	0	E.N.E.	6	(at 11 h.)	10 (at 11 h.).
29	W.	—	W.'S.	19–24	W.	25		31
30	N.N.W.	12–15	N.N.W.	8–12	W.'S.	6	(at Cranwell)	10 (at Cranwell).
31	W. light	—	W.	8–12	S.'E.	7	(Cranwell at 12 h.)	14 (Cranwell at 12 h.)

* Had blown all night from S.W.-W., *i.e.*, Hunstanton—4 miles away.

Office Station at Pulham and published in the British Daily Weather Report. Rough observations of visibility were also made at Holme, as referred to later.

Method of Mounting.—The records obtained were mounted on microscope slips and preserved for subsequent examination. The method of mounting, however, was not always the same; some of the earlier records were mounted in Canada Balsam, but the later ones were mounted dry, as it appeared possible that the balsam might affect the record and make the subsequent counting incorrect. As a matter of fact this was found to be the case, and the records mounted in balsam always gave a very much lower count than they should have done. This was ascertained to be due to the balsam, by examining some records part of which were mounted dry and part in balsam, also by observing the behaviour under the microscope of a record which was mounted dry, and balsam allowed to flow in under the cover-glass. In order to correct for this, as far as possible, an estimated figure is given for the records mounted in balsam obtained by multiplying the actual count by 7/3, which was found to

be about the ratio of particles mounted dry to a count of a record taken at the same time and mounted in balsam.

The number of particles per cubic centimetre of air is based upon a count under the microscope, and is not to be taken as absolutely correct, but rather as a minimum figure, since the counts were made of particles adhering to the glass of the jet apparatus and no allowance made for those which may have escaped; the latter were, however, probably not over 20 per cent. The damp approach-chamber was not in use at this time.

Wind.—The wind direction as observed at Holme is given, and also as observed at Pulham. Where the velocity at Holme is given it was measured at about 6 feet above the ground, by means of thistledowns timed over a length of 50 yards of smooth sand. As the wind direction was measured near the surface and the records taken near the surface, while the chief source of suspended impurity is also probably fires situated near the ground, it would seem that it is the wind near the surface which is to be considered the transporting agency. The vertical distribution of suspended matter is unknown at present, but it appears probable that most of the suspended matter is held within 200 or 300 feet of the ground. The wind velocity at 1000 feet is given for Pulham for comparison with the surface wind, the figures being taken from the Daily Weather Report.

The diameters of the dust particles given in Table I were measured by means of an eye-piece micrometer, using a 1/12-inch oil immersion objective, having a numerical aperture of 1·28. The limit of resolution for such an objective, based upon Airy's theory, would be about 0·216 micron, that is all particles of this size, or lower, would appear of the same diameter.

The average size of the particles as given in Table I, was about 0·5 micron and therefore well above the limit of resolution, so that when uniformity in size was noted, this uniformity was not the result of particles falling below the limit of resolution and producing spurious discs.

All records taken during the west winds showed a number of small spherical particles, which were completely absent during the north-east winds. These spherical particles were not uniform in diameter but varied considerably, from nearly 2 microns down. It is possible that they may have been fused ash particles, but if so they should be dense, and one would have expected them to settle more rapidly than the smaller, and more irregularly shaped, grains. It is of interest to note in this connection that small spherical particles are very common in the flue dust from boiler furnaces and are especially numerous in furnaces using pulverised coal.

The Sources of the Impurity Observed.

The results exhibited in Table I have been considered with reference to a journal of the direction and velocity of the wind at 13 h. and 18 h., at Pulham, in Norfolk, 40 miles to the south of Holme, and at Cranwell, in Lincolnshire, about the same distance to the west, from August 8 to August 31. Taken in conjunction with the local observation it gives a fair general idea of the distribution of the surface wind. The journal was computed from the British Section of the Daily Weather Report and need not, therefore, be reproduced here, but may be referred to in support of the provisional conclusions derived from the observations.

On August 13, after a change from E. to N.W., the wind was due W., blowing across the Wash to the point at which the sample was taken. The suspended matter in the air was, therefore, probably derived from the industrial centres of Yorkshire or the Midlands. In the evening of Wednesday, August 17, after a spell of southerly winds which terminated with a thunderstorm followed by a remarkably clear atmosphere, a wind set in from the east with a marked haze, and settled into N.E. for three days with persistent dense haze. On the 18th, two samples were taken in north-easterly wind which had blown into the Wash from the North Sea, and touched land first at the point of observation. The number of particles in the evening sample was greater than in the morning. The north-east wind and the haze continued for the 19th and 20th, but on the 19th a shift of wind more to the east with an increase of strength produced less haze. The wind was remarkably constant, both at Pulham and Cranwell, and the velocity was sufficient to carry the air over 1,000 miles in the three days. Leaving out of account the effect of passing steamers, as being out of the question, there appears to be no source of the suspended matter on this occasion except the Continent, and we may fairly conclude that it crossed the North Sea.

Between August 21 and 24 the wind got away to northerly or north-westerly with a relapse to N.E. on the 22nd, reverting to N. on the 23rd and N.W. on the 24th. There was thick haze all the time, becoming thick damp fog on the 23rd. No observations were made during the northerly weather for want of material, but in the N.W. wind of the 24th the observations were resumed and a new feature was disclosed. There were apparently spherical particles present in the record, with diameters up to 1·7 micron. It is not quite clear what the path of the wind was before reaching Holme; it may have come from the furnaces of the North-East Coast of England, but it may, on the other hand, have been the haze of the previous N.E. wind drifting back

again, though that is not very likely. The deposit of August 27 may have come from Hunstanton, as the wind was from that direction.

On August 28, at 9 A.M., after calm and a little rain, the wind came from N. with clear air, but at 15 h. a slight haze came with a veer to the N.E. in the surface wind. The clouds came from the south throughout the day.

On August 30 there was very clear air with a moderate wind from N.N.W. and on this occasion drops of liquid were found with the deposit which, after being mounted a month, developed into crystals, presumably of common salt. But this was the only one of the records which gave this result, and any inference from it is hazardous; the liquid drops seemed to be separate from the dust particles and may have been separately suspended in the air.

On August 31 there was haze with westerly wind which disappeared with a change to N.E. and rain; the haze followed a cold, clear night and was dense in the early morning with westerly wind; but it was shallow, because the tops of the trees were more visible than the bottoms. The haze got lighter by 1 P.M., with the wind still west. The wind was round to N.E. by 4 P.M. and calm with a few drops of rain at 8 P.M.: by then the haze had gone. The indications are too vague for any conjecture as to the origin of the impurities which formed the haze in this case.

It is probable that regular observations, at any place, with different winds, would give some indication of the most likely source of the dust; for example, the author has found that when the wind blows from the direction of London, samples of air taken at Cheam, in Surrey, invariably contain large numbers of suspended particles of the same size and general appearance as those forming the London haze. When the wind blows from the opposite direction it contains few such particles. The smoke produced in the manufacturing districts of England probably drifts over hundred of miles, under suitable conditions, producing an impure air in the depths of the country. This is a point of some importance, as it is usually assumed that by going a few miles outside the city pure air can be obtained, which is very far from being the case, under present conditions.

During a recent visit to Exmouth, the author noticed that the whole country was obscured by a well-marked haze, which produced a red sunset, and doubtless had its origin from the smoke of the manufacturing districts of the Midlands, as there had been a light wind from the north for some time. Unfortunately samples could not be obtained, but from the appearance of the haze there is little doubt that it was composed of solid particles.

Table II.—Number of Dust Particles in the Air according to Various Observers.

Observer.	Method of collection of dust and counting.	Place of investigation.	Number of particles per cubic centimetre.	Reference.
John Aitken	Aitken's dust counter*	Argyllshire	300/3000	'Trans. Roy. Soc. Edin.,' vols. 30–36
		London	48,000 to 150,000	
B. C. and M. C. Whipple	Agitation with water in Palmer's apparatus and counting in a cell under microscope†	Boston, U.S.A., ground level	4·2	'Amer. Jour. Public Health,' 1913, 3, 1139
		58th floor	<1	
Dr. Penteado Bill	Electrostatic precipitation	—	From 22 to <1	'Jour. Ind. Hygiene,' vol. 1, No. 7, 1919

* It is not certain what is counted in the apparatus. Nuclei other than dust, such as electrons, are included.

† When in water, as shown in present paper, the smaller particles are lost. As shown by Katz, Fieldner and Longfellow, 'Jour. Ind. Hygiene,' vol. 11, No. 5, the Palmer apparatus is about 20–30 per cent. efficient in removing dust from air.

A Table (Table II) is given here, showing the dust counts as obtained by other observers, using different methods. The extraordinary variation in the number of particles as given is remarkable, and points towards some uncertainty in the methods adopted.